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Citation for published version:
Ascui, F & Cojoianu, T 2019, 'Implementing natural capital credit risk assessment in agricultural lending', *Business Strategy and the Environment*, vol. 28, no. 6, pp. 1234-1249. https://doi.org/10.1002/bse.2313

Digital Object Identifier (DOI):
10.1002/bse.2313

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Business Strategy and the Environment

Implementing natural capital credit risk assessment in agricultural lending

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Abstract
Agriculture has critical impacts and dependencies on natural capital, and agricultural lenders are therefore exposed to natural capital credit risk through their loans to farmers. Currently, however, lenders lack any detailed guidance for assessing natural capital credit risk in agriculture, and are challenged by the fact that the relevant material risks vary considerably by agricultural sector and geography. This paper develops a natural capital credit risk assessment framework based on a bottom-up review of the material risks associated with natural capital impacts and dependencies for Australian beef production. It demonstrates that implementing natural capital credit risk assessment is feasible in agricultural lending, using a combination of quantitative and qualitative inputs. Implementation challenges include the complexity and interconnectedness of natural capital processes, data availability and cost, spatial data analytical capacity and the need for transformational change, both within lending organisations and across the banking sector.

Key Words
Natural capital; credit risk assessment; environmental credit risk; agricultural lending; beef production; Australia

This is the accepted version of the following article: Ascui F., & Cojoianu, T. (2019). Implementing natural capital credit risk assessment in agricultural lending. *Business Strategy and the Environment,* 1–16, which has been published in final form at https://doi.org/10.1002/bse.2313. This article may be used for non-commercial purposes in accordance with the Wiley Self-Archiving Policy: http://www.wileyauthors.com/self-archiving

1 Introduction

In recent years, the business and financial sectors have woken up to the implications of their impacts and dependencies on natural capital – the stocks of the world's renewable and non-renewable natural assets (e.g. ecosystems and natural resources) that yield flows of environmental goods and services (e.g. timber, food, flood mitigation) which directly and indirectly underpin the global economy and human wellbeing (Bebbington & Gray, 1993; Costanza et al., 1997; Costanza & Daly, 1992; Dyllick & Hockerts, 2002; Pearce, 1988; Schumacher, 1973; van den Belt & Blake, 2015). In 2012, around 40 international financial institutions signed the Natural Capital Declaration, committing to integrate natural capital considerations into their financial products, and their accounting and reporting frameworks, by 2020.[1] The Chairman of one of Australia's largest banks, NAB – which provides financial services to one in three of Australia's farmers – recently stated:

> "As a bank, we understand that the commercial opportunities available to our agribusiness customers are heavily dependent on the quality of their natural assets. …[T]hose who manage their natural capital well – their soil health, water, energy and biodiversity – tend to be more resilient and more productive over time. …*We need to manage our natural capital with the same diligence that we manage our financial capital*." (Henry, 2016, emphasis added).

However, NAB acknowledges that this will require a "significant step-change" in credit decision-making and the development of entirely new credit risk assessment methods, because "[t]o date, credit decisions to agribusiness customers have been based on standard banking considerations like cash flow, assets, risk analyses and banker-customer relationships" (NAB, 2018, p. 4). This is the challenge that we take up in this paper: in practice, how could a bank assess natural capital risks in agricultural lending? Taking Australian beef production as a case study, what are the most critical natural capital risks within this sector, and how could they be assessed? What data would be required, and are such data practically available? Through exploration of these questions, we develop a framework for natural capital credit risk assessment in agricultural lending. As with any inductive research, our proposed framework is not the only possible outcome, but it provides a starting point for both banking practice, and further research on natural capital credit risks in other sectors and geographies.

Australian beef production forms an important case study for two main reasons. Firstly, agriculture in general is at the front line in terms of society's direct impacts and dependencies on natural capital (KPMG, 2014), and livestock production in particular has been singled out as "one of the top two or three most significant contributors to the most serious environmental

[1] http://www.naturalcapitalfinancealliance.org/about-the-natural-capital-declaration/ (accessed 26 October 2016).

problems, at every scale from local to global" (Steinfeld et al., 2006, p. xx). Livestock grazing, plus feed crop production, now occupies 30% of the ice-free land surface of the planet, accounts for 8% of global human water use and is probably the largest sectoral source of water pollution, as well as a major driver of deforestation and land degradation, biodiversity loss and climate change (Steinfeld et al., 2006). Secondly, beef producers manage in excess of 75% of Australia's total agricultural land (ABARES, 2018) – around 296 million hectares – and are therefore key stewards of Australia's agricultural natural capital. The sector is also economically very significant, contributing A$13 billion or 23% of Australia's total value of agricultural production in 2015-2016 (ABARES, 2018)

Assessing natural capital risk in the agricultural sector presents a particular challenge compared with other industries, because the sector's impacts and dependencies on natural capital are mediated via thousands of individual farmers, as opposed to a relatively smaller number of corporate actors. In Australia, for example, 99% of the 134,000 farm businesses operating in 2012 were family owned (NFF, 2012). This means that the traditional levers used by the financial sector to influence environmental, social and governance (ESG) outcomes in other sectors (e.g. through listed or private shareholdings which provide an avenue for direct engagement with company boards, as well as the opportunity to exercise voting rights) – are not as applicable to the agriculture sector. Nevertheless, the financial sector is still strongly exposed to agriculture's natural capital impacts and dependencies, directly via lending to farmers, as well as indirectly via agriculture's foundational role in many other sectors' supply chains.

When it comes to lending in general – and particularly at the relatively small scale typical of loans to farmers (e.g. US$0.5-2 million, usually to buy land or equipment, or to provide working capital to smooth out fluctuations in cash flow) – there is a distinct lack of practical approaches or guidance available for natural capital credit risk assessment. A survey of 36 financial institutions in 2015 discovered that 42% claimed to be already integrating natural capital risks in credit risk assessments; but, on closer inspection, found no evidence that this was done systematically (Cojoianu, Hoepner, Rajagopalan, & Borth, 2015). Cited barriers to implementation included lack of awareness, unclear regulatory requirements, and most importantly, the lack of standardised industry- and geography-specific methods and information to support the quantification of natural capital risks (Cojoianu et al., 2015). Agriculture presents a particular challenge because the relevant natural capital impacts and dependencies vary by sub-sector and geography: for example, the soil conditions that are favourable to one crop type or production system may be quite unfavourable to another, or indeed for the same crop or production system in a different climatic zone (Dominati, Patterson, & Mackay, 2010).

In this paper, we respond to these challenges by developing a framework for implementing natural capital credit risk assessment for a particular agricultural sub-sector and geography: Australian beef production. The paper is organised as follows: in section 2, we review the literature on environmental credit risk assessment (ECRA), in order to situate the emerging concept of natural capital credit risk within existing theory and practice. Section 3 outlines our method for identifying key natural capital impacts, dependencies and resulting risks in Australian beef production, the results of which are described in detail in section 4. Finally, section 5 discusses the overall findings and conclusions that emerge from this analysis.

2 Environmental credit risk assessment

Credit risk can be defined as "the risk of an economic loss from the failure of a counterparty to fulfil its contractual obligations" (Jorion, 2007; Mengze & Wei, 2015, p. 159). Credit risk assessment traditionally involves quantitative and/or qualitative assessment of information on borrower characteristics – such as reputation, leverage, earnings and collateral – as well as other contextual factors which are considered to influence the risk of borrower default (Altman & Saunders, 1997; Caouette, Altman, Narayanan, & Nimmo, 2010).

Banks started incorporating some environmental risks into their credit risk assessment processes in the early 1990s (Coulson, 2002; Weber, Fenchel, & Scholz, 2008), driven by legislation such as the *Comprehensive Environmental Response, Compensation and Liability Act 1980* in the United States, which imposed remediation liabilities on the owners of contaminated sites. Such legislation created a direct, potentially uncapped, risk for banks taking possession of contaminated land which had been used as security for a loan (Coulson & Dixon, 1995). Banks also began to appreciate that they were exposed indirectly to environmental risks affecting the borrower, which could increase the risk of default on the loan (the magnitude of such risks is therefore capped at the amount of loan principal). Finally, banks became aware of the reputational risk associated with lending to industries or activities attracting negative publicity because of environmental issues.

Each of these types of risk – direct, indirect and reputational – is different in nature, requiring a distinct approach to risk assessment and management. Banks responded to the legal imposition of direct risks by undertaking rigorous environmental risk assessments of sites associated with borrowers in polluting industries; becoming more cautious in their lending; and requiring borrowers to provide additional security, guarantees or insurance to protect the lender from future liabilities (Coulson & Dixon, 1995; Delamaide, 2008). The existence of a direct risk is usually something that can be relatively easily determined and quantified (assigned a probability of occurrence and potential financial impact). Indirect risk, on the other hand, requires a different type of borrower-specific analysis that is potentially much wider-ranging in nature, reflecting the diversity of environmental risks affecting businesses in general (Dobler, Lajili, & Zéghal, 2014; James, 1994). As indirect risk affects the borrower's ability to repay a loan, it should in theory form part of the overall credit risk assessment process and be reflected in the borrower's risk rating and pricing of loans. However, measuring and quantifying such diverse risks presents significant challenges. Finally, reputational risk – "arguably the most difficult to identify and quantify financially" (Thompson, 1998, p. 245) – is usually addressed through high-level responsible lending policies that are linked with the bank's marketing and corporate social responsibility (CSR) strategies, rather than via explicit measurement procedures (Dell'Atti & Trotta, 2016; Mukherjee, Zambon, & Lucius, 2013).

ECRA has evolved in the past three decades, although the evidence suggests that, aside from consideration of direct risk, it is not yet highly sophisticated in practice. A survey of 57 UK banks in the mid-1990s found that although 87% included an appraisal of environmental risks as a part of their credit risk assessment procedures, "there are no signs in the current research that bankers are particularly interested in measuring things like externalities… [or] essential natural resources on which the enterprise is economically dependent" (Thompson & Cowton, 2004, p. 214). A 2002 study of a sample of ten European banks found that while all believed that environmental risks could impact bank profitability and should be reflected in loan pricing, they lacked any definitive means of measuring impact (Coulson, 2002). The report concluded, "In practice, most lenders stop short of assigning a value or margin to environmental risk and rely on 'experience as the best guide'" (Coulson, 2002, p. 2). A survey of 50 European banks in the mid-2000s found that they generally claimed to take environmental risks into account in the credit rating stage, but "there is still a lack of a systematic and quantitative integration of these kinds of risk in all phases of the credit risk management process" (Weber et al., 2008, p. 157). In addition, the survey found considerable variation in approaches taken by banks, from a single assessment question to applying sophisticated risk evaluation tools (in a minority of cases). Furthermore, within the vast scope of indirect risks, banks tended to concentrate on just two areas: the impacts of mandatory environmental regulations, and changes in buyer or consumer attitudes (Thompson & Cowton, 2004; Weber et al., 2008).

The turn towards 'natural capital' thinking in the financial sector since 2012 (Natural Capital Declaration, 2012) poses further challenges for ECRA, because it significantly extends the scope from environmental *impacts* to include *dependencies*. We therefore use the term 'natural capital credit risk assessment' to denote this enlarged scope, which primarily involves indirect risk. We follow the Natural Capital Protocol in defining an impact as "[t]he negative or positive effect of business activity on natural capital" while a dependency is "[a] business reliance on or use of natural capital" (Natural Capital Coalition, 2016, pp. 16–17). Under this framing, contaminated land can be viewed as a typical example of a negative *impact* on natural capital (potentially affecting the quality of soil, water and ecosystems/biodiversity) as a result of pollution discharge as an *impact driver*, which gives rise to a socially mediated business *risk* (legally-imposed remediation obligations). Dependencies are quite different, and often taken for granted: businesses may depend on inputs of natural capital in the form of land, water, energy or materials, as well as a vast range of ecosystem services, such as climate regulation, pollination, flood protection and waste assimilation. Where these inputs and services are priced (either in markets or through regulation), they are likely to feature in existing risk assessment metrics; but the problem is that many natural capital dependencies are either not priced at all, or not priced at their full social cost (Helm, 2014; van den Belt & Blake, 2015). Such dependencies – as well as similarly mispriced impacts – may therefore carry a risk of being priced or otherwise affecting the business in future, whether directly, indirectly or through the supply chain, thus translating into indirect risk for a lender.

The sectors most likely to be both highly dependent on natural capital, and with high potential for impacts on natural capital, are typically primary production industries such as agriculture, fisheries and forestry (KPMG, 2014; Natural Capital Coalition, 2016; van den Belt & Blake, 2015). Unfortunately, these sectors have highly complex and diverse natural capital impacts and dependencies, which have received relatively little attention from ESG analysts: a survey of 66 financial research providers in 2015 (Cojoianu et al., 2015) found that only nine claimed to have any methodological expertise in assessing natural capital risks in agriculture; furthermore, this expertise was limited to whole-sector analysis, rather than the ability to provide more granular assessment of risks at the individual farm level. Although the Natural Capital Coalition – an outgrowth from the influential 'TEEB' (*The Economics of Ecosystems and Biodiversity*) reports (TEEB, 2008) – has recently developed the Natural Capital Protocol, a standardised framework for businesses to identify, measure, and value their impacts and/or dependencies on natural capital, along with a supplement for financial institutions (Natural Capital Coalition, 2016, 2018), neither of these provide specific guidance for the agricultural sector, or for credit risk assessment. Rather, they each provide generic approaches, covering (in the case of the financial sector supplement) all financial services and asset classes.

There are also very few examples in the academic literature of systematic methods for assessing natural capital credit risks in agriculture, whether for lending or investment purposes. Georgopoulou et al. (2015) point to the almost complete absence of methods for the assessment of just one important environmental risk factor – climate change, which can be framed as a natural capital risk arising from agriculture's dependency upon current climatic conditions – in bank lending. Dominati, Patterson, & Mackay (2010) note that the natural capital and ecosystem services provided by soils remain poorly understood, despite their critical importance. Zeidan et al. (2015) propose a sustainability credit scoring system for the sugar industry in Brazil, which could be applied at the individual loan level. However, it aims to assess broader sustainability (including economic and social as well as environmental dimensions) rather than focussing on natural capital.

In summary, despite the fact that ECRA has now been practiced by banks for nearly three decades, the evidence suggests that assessments tend to focus on direct risks and specific, well-understood indirect risks such as mandatory regulation and market changes. The shift towards thinking about natural capital dependencies as well as impacts has created a need for new approaches to assessing credit risk, especially for primary production sectors such as agriculture. Our paper aims to provide a framework for implementing natural capital credit risk assessment in agriculture via an illustrative case study that evaluates the materiality of natural capital impacts and dependencies for Australian beef production, and how such risks could be assessed by a lender.

3 Method

3.1 Approach and assumptions

This paper explores how a new concept proposed by the financial sector – natural capital credit risk assessment – could be articulated in practice. In the absence of any existing framework for natural capital credit risk assessment in agricultural lending, we have taken a grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998) approach to exploring the issue, in order to develop new understanding based on iterative interpretation of empirical data, as opposed to hypothesis testing.

Nevertheless, some conceptual starting points must be acknowledged. The conventional credit risk management process can be divided into five phases, comprising rating (or risk identification), costing (or risk evaluation), pricing, monitoring and work-out (Weber et al., 2008). We focus on the rating and costing stages, as essential first steps towards incorporating natural capital within credit decision-making. Our primary aim was therefore to identify, as comprehensively as possible, the natural capital risks likely to be relevant (i.e. material) in an individual credit risk assessment, within the case study sector and geography (Australian beef production). This is broadly consistent with the 'materiality assessment' step in the generic approach to natural capital assessment set out in the Natural Capital Protocol and its finance sector supplement (Natural Capital Coalition, 2016, 2018). A secondary aim was to assess, for each material risk, measurement options and potential data sources, in order to appreciate whether evaluating the risk might be practicable. As the availability of measurement options and data sources could vary considerably between lenders, the latter exercise was intended to be purely illustrative. We kept an open mind as to whether risk evaluation could be quantitative or qualitative, noting that ECRA is often based on qualitative judgements (Coulson, 2002).

Other important assumptions include the perspective, time-frame and understanding of materiality and risk. We chose to view risk strictly from a lender's perspective, which could differ from a borrower's or a societal perspective. For example, a risk considered to be material to society might be immaterial to a borrower if it is unlikely ever to be priced, regulated or otherwise capable of affecting the operation of the borrower, or the reputation of the lender.

Materiality can be interpreted in different ways. In line with the Natural Capital Protocol finance sector supplement (Natural Capital Coalition, 2018), we interpret materiality as anything that has reasonable potential to significantly alter the decisions being taken. In the case of natural capital credit risk assessment, the decision is whether or not to offer credit to a particular applicant, and on what terms. This is essentially an assessment of whether the expected risk of offering the loan is commensurate with the expected return, or the lender's average return for similar loans. This implies that material natural capital risks are those which have reasonable potential to significantly alter the financial health of the farming business, for example by increasing costs, reducing productivity, or reducing the price of outputs such as meat. While direct risks (e.g. of land offered as loan collateral being contaminated) and reputational risks (e.g. the possibility of negative publicity associated with lending to a land-clearing project associated with high biodiversity impacts) might factor in the loan decision, we focus on the indirect risks that have reasonable potential to affect the financial health of the farming business.

Risk can be regarded as referring to the level of uncertainty of outcomes that are significantly different to expectations, whether in a positive or negative direction. However, common usage tends to focus on outcomes that are negative, or worse than expectations. This usage also fits with credit as a form of financing that is only exposed to negative outcomes, in contrast to equity investment, which is exposed to both positive and negative results. We therefore focus on the risks of negative outcomes: a risk was considered material if it was clearly capable of causing a significant negative deviation from expected (usually historical average) expectations for yields, prices or costs, either in the short- or long-term. It was not practicable to set quantitative thresholds for significance, but where possible we have provided quantitative evidence in support of our judgment. As risk is the product of its probability of occurrence and the magnitude of its impact, we took both these dimensions into account: a risk was considered material if *either or both* its probability of occurrence and impact were high. Finally, as risks may have different levels of materiality over different time horizons, we focus on longer-term risks, defined as 10-20 years into the future, reflecting typical loan periods for land purchase agricultural loans in Australia.[2]

3.2 Case study definition

Cattle can be raised primarily on pasture, and/or in feedlots where they are fed a managed diet supplemented with grain. Pasture-fed cattle are often fattened up in feedlots prior to slaughter, particularly for high-quality export markets (PwC, 2011). Grazing and feedlot production have

[2] Interview with Agribusiness Finance Manager, 12 August 2016.

different impacts and dependencies on natural capital, and often they are separate businesses. In addition, grazing on irrigated pasture, or the use of irrigated feed crops, introduces additional natural capital impacts and dependencies, compared with rain-fed pasture grazing. For simplicity, we focus our case study exclusively on the latter. It remains broadly representative of the Australian beef cattle industry, which relies mainly on rain-fed pasture, although some pasture and feed crop irrigation is used in southern parts of the country, and about 2% of cattle are in feedlots at any given time (ALFA, 2013).

3.3 Data sources

Potential natural capital risks and their materiality for Australian beef production were assessed by iterative triangulation of empirical evidence from multiple sources: a review of relevant academic papers; a review of publications and online material from Australian industry-specific bodies such as Meat and Livestock Australia (MLA) and relevant government agencies; and discussions with Australian agribusiness experts, credit managers and environmental finance professionals. The latter included both formal interviews (4) and informal discussions over a period of three and a half years, including an invitation-only workshop with 30 international experts, and practitioner peer review of the framework presented in this paper by an environmental finance professional and two agribusiness experts. A first stage of the research, which was conducted as part of a larger project covering three other sectors in addition to beef production, produced a 'long list' of natural capital impacts and dependencies for all four sectors, while the second stage reduced this to a 'short list' of more specific risk factors applicable to beef cattle production in particular. The same sources were consulted for evidence of potential measurement options and data sources to evaluate the identified risks. Typically, industry body publications and expert inputs proved the most useful in validating the materiality of identified risks to the industry, given their focus and access to information specific to the Australian context.

All identified risks were sorted into emergent categories which were constantly re-evaluated as new evidence emerged, ceasing only when a point of 'category saturation' (Strauss & Corbin, 1998) was reached, where the extant data was found to fit the generated categories in a way that appeared meaningful and relevant (the framework set out in Table 1), and further data collection (including practitioner peer review) failed to generate new categories. Nevertheless, it should be noted the analysis aimed to identify the key risks at sector level: the heterogeneity of individual farms means that there may always be scope for additional risks at the farm level, which have not been identified as material at the sector level (and vice versa).

4 Results – natural capital credit risks in Australian beef production

This section provides, for each identified key risk, a brief explanation of what it is and why it is material, and what measurement options and data sources are available to evaluate these risks, either quantitatively or qualitatively (Table 1).

[Table 1 about here]

4.1 Water availability

The water available to a farm can include rainwater, on- and off-farm surface water and sub-surface water. We focus in this section on rainwater availability, as most Australian beef production is dependent on rain-fed pastures. The impacts and dependencies associated with the use of surface and sub-surface water for livestock drinking are considered separately in section 4.2.

The level of rainfall is the biggest predictor of agricultural productivity in a given year, and long-term averages are a key determinant of both land prices (Land Commodities, 2012) and sustainable stocking rates. The financial impact of water availability on Australian beef cattle production can be inferred from the fact that on average, in 2013–14, cattle farms affected by drought experienced a 4% increase in debt levels, with 54% of the increase in principal being due to cash flow shortfalls (ABARES, 2015). From a lender's perspective, it is critical that the level and reliability of income from the planned farming activity (which in the case of beef production is largely determined by the sustainable stocking rate) can support repayment of the loan (which is typically a proportion of the cost of the land). Lower stocking rates and flexible management can compensate for lower/more variable rainfall: for this reason, beef production is widely distributed across different rainfall zones in Australia. Rainwater availability risk for beef production can therefore be more specifically defined as the risk that rainfall will be insufficient to produce the biomass required to meet livestock grazing needs, at the target stocking rate.

Rainwater availability for any crop, including pasture, is a function of four inter-related factors (Land Commodities, 2012): **quantity**; **timing**; **reliability** (the variability of both quantity and timing); and **water use efficiency** (the proportion of rainfall which becomes available to the pasture itself, which is a function of various factors including soil characteristics, drainage, topography, timing of rainfall events, climatic conditions after rainfall, nitrogen supply, weed cover and pasture characteristics).

Ideally, all of these factors would be taken into account in measuring rainwater availability risk, and the level of risk would be related to the target stocking rate. Various measurement options are available, ranging from crude high-level indicators (e.g. annual average rainfall) to bespoke modelling of monthly average rainfall and pasture availability against animal feed demand.

Rainfall data is widely available in Australia from the Bureau of Meteorology, although on-farm records could provide more accurate information in certain cases. Outputs from region-specific climate models can provide an indication of whether rainfall availability risk is likely to increase or decrease over time. Pasture water use efficiency can be estimated from field measurements of pasture biomass at the beginning and end of the growing season, grazing records and rainfall data; and benchmarked against peers or best practice targets. The likely future change in water use efficiency risk could be assessed by extrapolation from past trends or assessment of planned management interventions, such as plans to build and maintain soil nutrients, or to improve pasture species composition to maximise the quantity and quality of pasture growth for the expected rainfall availability.

4.2 Water use

The consumption of water can be regarded as having an impact on natural capital when the water used is non-renewable (i.e. 'fossil water'), extracted beyond its renewal rate, or diverted away from other ecosystem uses (Peters, Wiedemann, Rowley, & Tucker, 2010). As Australian beef production relies mainly on rainwater for pasture growth (excluded because it is renewable, cannot be used beyond its renewal rate, and is generally not diverted from other uses), consumption impacts are mainly applicable to livestock drinking water. However, similar observations may apply to water used for irrigation, where applicable.

Livestock cannot survive without sufficient drinking water: this therefore constitutes a critical natural capital dependency, giving rise to a risk that the available water supply may be insufficient to meet total water demand (including losses) at the target stocking rate. Measuring this risk presents a challenge, however: livestock drinking water in Australia is usually sourced from small dams on farm watercourses, and artesian boreholes, and daily water requirements and intake by livestock vary depending on class of stock, production status, age and condition of the animal, dry matter intake, quality and nature of feed, climatic conditions, and the quality of the water. The average daily water requirement for Australian beef cattle is around 45 L/head, but this can go up to 60 L/head on hot days.[3] Furthermore, the amount of water actually used for stock watering includes not only the amount consumed by animals, but also the losses incurred in supply (for example through direct wastage, leaks and evaporation). A study on Australian beef production by Wiedemann et al. (2015) estimated annual water supply losses on a full life-cycle basis to be around 190 L/kg live weight (LW) in 2010 – roughly double the direct drinking water amount. Relating variable demand to the availability of surface and sub-surface water flows and reservoirs would require sophisticated hydrological modelling. However, average consumption, measured as the average total water (including losses) consumed, divided by livestock numbers, normalised by reference to a standardised animal,

[3] https://futurebeef.com.au/knowledge-centre/nutrition/water-requirements/ (accessed 15 August 2018).

such as ‘dry sheep equivalent’ (DSE), could be used to provide a relative measure of risk exposure, if benchmarked against peers in similar rainfall zones.

Average consumption, combined with the degree to which the water used meets the criteria for impact, could also be used to measure impact risk. The likely future outcome for both risks could be extrapolated from past trends, or be based on analysis of planned management interventions, such as reducing water losses by capping free-flowing artesian wells, installing efficient water storage and distribution systems, providing shade and investing in cattle breeds with lower water requirements (Higgins, Moser, & Schmidt, 2016).

4.3 Water quality

The quality of livestock drinking water can affect daily water requirements, livestock health and productivity (Hamlyn-Hill, 2016). It therefore constitutes a separate dimension of a farm’s dependency on water. Any farming activities which affect the quality of a water stock or flow can also constitute an impact on natural capital.

Key water quality indicators which are critical for livestock health include total dissolved solids (TDS), calcium, nitrate and nitrite, fluoride, chloride, acidity (pH), pathogens and parasites, and agricultural chemicals such as pesticides and herbicides. A lender could potentially evaluate the baseline level of risk by examining historical on-farm water quality data, with reference to the frequency of exceedance of critical thresholds for each indicator. For example, a level of TDS greater than 2,000 mg/L will increase thirst and thus daily water requirements (thus increasing water consumption risk) whereas a level over 5,000 mg/L is severe, leading to potential loss of production and decline in animal health and condition (Hamlyn-Hill, 2016). Alternatively, overall water quality risk could be assessed qualitatively, by evaluating the farmer’s capability to monitor water quality, and to take appropriate risk management actions, such as moving animals to different watering locations and preventing fertiliser run-off into water reservoirs with improved timing and quantity of application.

4.4 Temperature extremes

While temperature *per se* does not strictly meet the definition of natural capital, we include it in our analysis because agriculture clearly has a critical dependency upon certain temperature ranges, resulting in a material risk of exposure to extremes. Livestock can be affected by both cold and heat stress, which can affect mortality rates, reproduction, productivity and animal welfare (the latter is considered separately, in section 4.12). Cattle require more drinking water when exposed to heat stress, which can exacerbate risks associated with water use and quality.

Heat and cold stress are in fact not only dependent on temperature, but on combinations of air temperature, humidity/rainfall, wind speeds and solar radiation. The effect on an individual animal depends on further factors such as the breed, condition, physical activity, quality and quantity of feed and water intake, and coat colour (Wang, Bjerg, Choi, Zong, & Zhang, 2018). In Australia, beef cattle producers mitigate heat stress risk by running tropically-adapted *Bos indicus* breeds in hotter northern areas, and ensuring that calving takes place during the cooler months of the year.

A number of different metrics are available to measure heat and cold stress, differing in their complexity, data sources and factors that they take into account. For example, the combined temperature-humidity index (THI) is a simple metric calculated from air temperature and relative humidity, whereas the Heat Load Index (HLI) is a more complex metric that can be combined with factors such as the breed, coat colour, condition, shading and drinking water temperature to generate more specific heat risk assessments (Wang et al., 2018). Lenders could assess exposure to heat and cold stress by analysing historical index data for the region and consulting outputs from region-specific climate models for projected changes in the frequency and severity of heat and cold stress events.

4.5 Extreme weather

The extreme weather-related events of most significance for agriculture include droughts, floods, storms and bushfires. The rate of occurrence of these events is influenced both by climate change and cyclical phenomena such as the El Niño-Southern Oscillation (El Niño being associated with droughts across much of Australia, while La Niña is associated with increased rainfall, often leading to floods). Real farm GDP declined on average 12.6% during the last five El Niño events (NAB, 2015). During drought years, cattle slaughter rates typically increase, as farmers try to reduce stocking rates to preserve pastures. This can lead to increased costs to re-stock once the drought ends, and the resulting shortage of adult animals can lead to national stock decline. Floods can also have significant impacts – in February 2019, extreme rainfall after five years of drought in northern Queensland is estimated to have killed up to half a million cattle, or nearly 2% of the national herd.[4]

Extreme event risks can be mitigated to some extent by geographic diversification. However, events such as storms, floods and droughts often occur over large areas. At the individual farm level, mitigation options include crop and/or livestock diversification (e.g. growing grain as well as sheep and cattle) and using climate forecasts to inform production decisions.

Agricultural lenders' credit risk models could incorporate aspects of insurance modelling, taking historical frequencies of impacts for a given region into account, and adjusting the probability of these risks up or down over the longer term according to long-term forecasts from reputable institutions (e.g. Australian Bureau of Meteorology).

[4] https://www.theguardian.com/australia-news/2019/feb/11/up-to-500000-drought-stressed-cattle-killed-in-queensland-floods (accessed 18 February 2019).

4.6 Soil quality

Agricultural activity relies heavily on the underlying quality of the soil, and also significantly affects soil quality. Both impact and dependency soil quality related risks translate directly into decreased agricultural productivity, long-term natural capital degradation and depreciation in land value.

The multi-dimensional nature of soil quality means that, in an ideal world, at least seven different indicators would be monitored: acidification, soil organic carbon, water erosion, wind erosion, salinity, nutrients, physical condition and biological condition (Sbrocchi et al., 2015). Physical and biological soil condition is very difficult to monitor at the extensive scales relevant to Australian beef cattle farming, and therefore excluded from our analysis, while nutrients are addressed in relation to the use of fertilisers to supplement nutrient deficiencies, in section 4.7. In the remainder of this section we discuss the other five indicators.

Soil acidification is a slowly-occurring natural process which is accelerated by agriculture, mainly due to excessive use of nitrogen-based fertilisers, and because the product removed (e.g. pasture as it is grazed and converted to meat) is alkaline. More than 80 million ha of Australian agricultural land is classed as acidic, with 40% of this being highly acidic (pH<4.0) (Kunhikrishnan et al., 2016). Soil acidity results in poor root growth and restricted access to water and nutrients. Nitrogen-based fertilisers are rarely used in Australian beef production (see section 4.7), but acidification may still occur due to leaching of nitrogen that has been sequestered in the soil by legumes, the growth of which may be promoted either deliberately, or as a side effect of phosphorus-based fertiliser use. Acidification rates for well-managed perennial pastures are relatively low.[5] For improved pastures, careful use of appropriate fertiliser and the application of lime can mitigate soil acidification. Soil acidity or pH can be measured easily with hand-held sensors or by laboratory analysis of soil samples, and various sources of soil acidification mapping data are available in Australia.[6]

Soil organic carbon (SOC), and the ability of soil to store it, is regarded as an important basis for soil fertility, and consequently, pasture yields. It is also an important component of the global carbon cycle, with potential to provide either substantial additions or removals to atmospheric CO_2 levels, depending on how it is managed. Across Australia, the total stock of organic carbon in the top 30 cm of soil is estimated to be 19-32 GtC (Viscarra Rossel, Webster, Bui, & Baldock, 2014). Unimproved grazing land, typical of northern Australian cattle production, has the lowest SOC of any agricultural land type, estimated at 24 tC/ha. Nevertheless, because of the

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[5] https://www.mla.com.au/research-and-development/Environment-sustainability/Sustainable-grazing-a-producer-resource/healthy-fertile-soils/chemical-fertility-soil-nutrition/soil-acidification/ (accessed 15 August 2018).

[6] E.g. see https://data.gov.au/dataset/farms-with-significant-degradation-problems-soil-acidity-1998-1999 (accessed 9 January 2019).

very large extent of such land, it makes up the largest pool of soil carbon of any agricultural land use in Australia (Viscarra Rossel et al., 2014).

SOC is difficult to measure accurately, requiring laboratory analysis of properly prepared soil samples. However, an indication of a farm's average level of SOC could be obtained from the Australia-wide map produced by Viscarra Rossel et al. (2014).

Dryland **salinity** occurs when the concentration of soluble salts near the soil surface is sufficient to reduce plant growth. Dryland salinity develops when a supply of water and a store of salt in the soil meets the ground surface, typically due to clearing for agriculture and/or the replacement of deep-rooted perennial vegetation with shallower rooted annual crops. Up to 17 million hectares of mostly agricultural land in Australia is thought to be at risk of developing salinity problems by 2050 unless effective action is taken to mitigate this risk (ABS, 2010). Salinity is also thought to have caused a 50% decrease in the numbers of wetland bird species, and is threatening 450 plant species with extinction (ABS, 2010).

Salinity is usually assessed by measuring the electrical conductivity of the soil, which can be done in the field or a laboratory. The likely impact of salinity on pasture growth can then be assessed by reference to the soil type and pasture species.[7]

Poor grazing management can remove protective ground cover, leaving the soil exposed to **water and wind erosion** which can in turn impact pasture yields by reducing the capacity of the soil to retain water and nutrients. MLA recommends maintaining at least 70% ground cover with a high proportion of perennial species, and up to 100% ground cover on steep slopes. Lower ground cover can therefore be an indicator of potential soil erosion risk – 20% ground cover is estimated to lead to 8.5mm/year soil loss, as opposed to 0.3mm/year at 70%.[8] Ground cover is usually assessed visually, either in the field or by use of aerial or satellite imagery.

Overall, soil quality is clearly both a critical natural capital dependency and source of impacts for most forms of agriculture, therefore it should feature in natural capital credit risk assessment. However, this is challenging, due to the complex, multi-dimensional and interlinked nature of soil quality. Nevertheless, a lender could assess the current state of the above indicators to start to evaluate the current level of exposure to key risks. If a sufficiently long time-series of reliable soil data can be established, future trends could be extrapolated. Otherwise, a more qualitative assessment could be made of the farmer's ability to manage soil quality issues into the future.

[7] See http://www.makingmorefromsheep.com.au/healthy-soils/tool_6.5.htm (accessed 15 August 2018).
[8] https://www.mla.com.au/research-and-development/Environment-sustainability/Sustainable-grazing-a-producer-resource/climate-variability-using-water-wisely/maintain-ground-cover/ (accessed 15 August 2018).

4.7 Fertiliser use

Fertiliser is a generic term for a range of soil additives which enhance productivity by supplementing mineral deficiencies and increasing the availability of nutrients for plant growth, or improving other aspects of soil health. Generally, the most important nutrients are nitrogen (N), phosphorus (P), potassium (K) and sulphur (S).

Fertiliser use has significant environmental impacts in several ways: it represents consumption of various natural resources and energy; it can result in greenhouse gas (GHG) emissions in both production and consumption; and it has the potential to both positively and negatively impact other natural resources, notably soil, water and biodiversity. It is also economically very important: fertiliser use is estimated to add $12.7 billion in increased productivity to the Australian agriculture sector (Ryan, 2010). In Australia, fertiliser is mainly used in southern beef production, where it accounts for nearly 9% of annual farm costs (as opposed to less than 1% for northern producers).[9] The main type of fertiliser used in Australian beef production is phosphorus-based, although nitrogen-based fertilisers may also be used in the production of grain (either as feed, or in mixed farms which alternate between cereal cropping and livestock grazing) (Wiedemann et al., 2015; Wiedemann, McGahan, Murphy, & Yan, 2016).

Farms relying on fertiliser to achieve their target stocking rates are therefore dependent on the natural assets that are used in fertiliser manufacture (mainly minerals and fossil fuels), giving rise to a risk that these non-renewable natural capital assets may be priced at higher levels in future (e.g. reflecting rising extraction costs, or their true substitution costs). The cost of phosphorus-based fertilisers doubled over the decade 2000-2010, reflecting the depletion of low-cost reserves (Simpson, Richardson, & McLaughlin, 2010). This dependency risk could be evaluated by reference to the farm's historical and projected fertiliser use, by type, and 'stress-testing' the resulting impact on farm finances by imputing a price reflecting substitution costs for the relevant natural capital inputs.

The upstream impacts associated with fertiliser use are likewise driven by the quantity of each type of fertiliser used, but downstream impacts are strongly influenced by the way in which it is applied. The main downstream impact associated with phosphorus based fertilisers occurs when phosphorus is incompletely absorbed by plants in the application zone, and ends up in waterways, where it can cause algal blooms and eutrophication. At a global level, human perturbation of the phosphorus cycle has been identified as a critical 'planetary boundary' issue, with anthropogenic inputs exceeding the natural background rate by around eight times (Rockström et al., 2009). Geological records show that large-scale anoxic events, potentially explaining past mass extinctions of marine life, occur when critical thresholds of phosphorus

[9] http://www.agriculture.gov.au/abares/research-topics/surveys/beef#data-and-other-resources (accessed 20 August 2018).

influx to the oceans are exceeded, potentially by as little as 20% of the natural background rate (Rockström et al., 2009). The frequency of reportable fertiliser-related water pollution events could be monitored as an indicator of downstream fertiliser application risk, particularly in areas with low P-sorption capacity soils (Simpson et al., 2010).

4.8 Contamination and waste

The agricultural sector has long been regarded as a potential candidate for increased environmental credit risk attention (Coulson, 2002), due to the fact that land offered as collateral may be contaminated with various wastes. Although Australian beef production increasingly relies on its 'clean and green' image (PwC, 2011) and accounts for a large part of Australia's 27 million hectares of certified organic farmland (Australian Organic, 2017), past use of organochlorine pesticides, for example to control ticks, has led to very high levels of contamination at some former cattle dip sites (Yapp et al., 2001). However, these and other significant contamination risks (such as the presence of asbestos in building materials) are likely to be already taken into account in a lender's ECRA procedures.

4.9 Biodiversity

Biodiversity and ecosystems are fundamental elements of natural capital, providing a wide range of ecosystem services to society (TEEB, 2008). Agriculture has both critical dependencies on biodiversity, and the potential to have serious impacts.

The risk of impacts is particularly high in Australia, due to the existence of globally unique and threatened biodiversity, with more than 1,700 species and ecological communities known to be at risk.[10] The key threats to biodiversity include agricultural practices which lead to loss, degradation or fragmentation of habitats, changes to water flows and quality, altered fire regimes and the introduction of invasive pests, diseases and weeds. Nationally threatened species and ecological communities are protected in Australia under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), which controls actions likely to cause significant impacts; further protections also exist under state legislation. Compliance with the EPBC Act can create additional costs for farming businesses, such as having to undertake environmental impact assessments or being prevented from taking certain actions such as land clearing, and contravention of the Act can lead to civil penalties such as remediation orders.

Given the existence of this legislative framework, a first step towards evaluating the risk of significant impacts on biodiversity could be to identify whether the farm includes any threatened ecological communities, or habitat for threatened species. A variety of resources exist that can help to identify whether a farm is in a biodiversity 'hotspot' or within the known

[10] http://www.environment.gov.au/biodiversity/threatened/species (accessed 23 March 2017).

range of a threatened species or community.[11] However, it should also be acknowledged that the existence of such biodiversity can be an indicator of ecological richness, and considered a potential asset, if well managed. A second step – essential if a farm includes threatened species or communities, and desirable in general – could therefore be to evaluate the effectiveness of the farm's biodiversity management. In practice, this is extremely challenging to monitor, and therefore an evaluation would most likely have to be qualitative in nature. Indicators of best-practice biodiversity management might include having undertaken activities such as mapping, conserving and regenerating remnant patches of native vegetation; creating buffers and setting land aside for biodiversity; creating corridors between areas of relatively undisturbed habitat; and controlling invasive weeds and pests (see section 4.11).

A separate assessment could be made of whether any key dependency species or habitats are under threat. For example, bee populations in many countries have declined significantly in recent decades, and some Australian beef production (on improved pastures with high clover or other legume content) is relatively more dependent on insect pollination than production on wind-pollinated grasses.

4.10 Pasture composition

Sustainable pasture growth is essential for beef producers. Inadequate pasture growth can result in increased costs to purchase hay or grains as alternative food sources, more expensive inputs such as fertiliser and herbicides, or more frequent pasture re-sowing. Pasture growth and quality is influenced by many factors considered elsewhere in this paper, such as soil quality (section 4.6), temperature (section 4.4), rainfall (section 4.1), pasture water use efficiency (section 4.2), weeds (section 4.11) and ground cover (section 4.6). In this section we focus on species composition, which contributes to the maintenance of sustainable pasture and is influenced by actions such as the management of grazing pressure, application of fertiliser and pasture re-sowing. Pasture composition dependency risk can therefore be defined as the risk of lower productivity, or higher costs, due to loss of optimal pasture composition.

Evaluating pasture composition typically requires resource-intensive on-site visual assessment, although satellite-based evaluation may be available in future.[12] In addition, the optimal pasture composition depends on soil characteristics, climatic conditions, fertiliser application and stocking rate. A practical measure of pasture composition risk could be the proportion of a farm in 'C' or 'D' condition according to the 'ABCD' standardised qualitative method for categorising land grazing condition (Chilcott, Paton, Quirk, & McCallum, 2003), which is widely used in Australia. This classes land into one of four grades, from 'A' (good) to 'D' (very poor),

[11] See for example http://www.environment.gov.au/biodiversity/conservation/hotspots/national-biodiversity-hotspots and http://spatial.ala.org.au/ (accessed 11 August 2017).
[12] See for example https://digitalagricultureservices.com/ (accessed 27 August 2018).

based on a combination of pasture composition and ground cover, erosion, weeds and the extent of woodland thickening.

4.11 Weeds

Weeds, along with pests and diseases (section 4.12) can be seen as 'negative dependencies' or 'ecosystem dis-services' (Swinton, Lupi, Robertson, & Hamilton, 2007) that result in reduced animal or plant health and productivity if farmers do not take appropriate action to mitigate their impacts. They can also have significant impacts on other forms of natural capital such as biodiversity, soil or water quality.

The financial impact of weeds on a farming enterprise depends on the type of agriculture as well as pasture type, livestock system, weed species and environmental conditions. In grazing systems, the major cost usually arises from lost production due to a reduction in stocking rates, as opposed to direct control costs. The total economic loss associated with weeds in the beef industry was estimated at A$883 million in 2003/2004, representing 11% of the industry's gross value of production (Jones & Sinden, 2006).

As with pasture composition (section 4.10), the proportion of a farm in 'C' or 'D' condition could be used as a proxy for weed risk, particularly where this proportion is increasing over time. 'C' condition typically includes the obvious presence of weeds and >50% bare ground at the end of the growing season, while 'D' lands typically have weed infestations covering significant areas, severe erosion and large bare areas (Karfs, Abbott, Scarth, & Wallace, 2009; Pettit, 2011).

4.12 Pests and diseases

Australia is free from many of the world's most impactful diseases, such as foot-and-mouth disease, which, it has been estimated, could cost approximately $7.1 billion for a small outbreak controlled in three months.[13] Nevertheless, the top 17 endemic pests and diseases in Australian beef production are estimated to cost the industry $941 million per annum (GHD, 2015). These include i) cattle ticks, estimated to cost the industry approx. $161 million/year; ii) Bovine Viral Diarrhoea Virus, estimated to cost $114.5 million/year, and iii) Buffalo Fly, estimated to cost $97.8 million/year (GHD, 2015).

The current level of pest and disease risk could be evaluated by reference to historical incidence levels, preferably disaggregated by individual pest/disease. The farm's current incidence level could be benchmarked against similar peers or industry-wide benchmarks, with data sourced from producer and/or processor records. A number of accreditation schemes in Australia include requirements on biosecurity practices and monitoring, and could therefore be used as evidence that the producer is managing pests and diseases risks effectively. These

[13] http://www.agriculture.gov.au/pests-diseases-weeds/animal/fmd (accessed 11 August 2017).

include the MLA Livestock Production Assurance (LPA) scheme, JBS Farm Assurance and Animal Health Australia Johne's Beef Assurance Score self-assessment tool.[14]

4.13 Animal welfare

The health and welfare of cattle contributes to farm productivity and is also important for maintaining reputational capital, at the level of the farm as well as the industry as a whole. The risks arising from non-compliant animal welfare practices include decreased farm productivity and regulatory, legal and reputational impacts, which could result in exclusion from the supply chains of certain retailers or countries receiving beef exports.

All Australian states regulate animal welfare standards in their jurisdictions through a state-specific Animal Welfare Act.[15] The Australian Animal Welfare Standards and Guidelines for Cattle (Animal Health Australia, 2016) were endorsed in 2016 and are in the process of being mandated in state regulations.[16] The standards state that cattle should be provided with adequate nutrition, sufficient water of suitable quality, social contact with other cattle, sufficient space, procedures to minimise stress and the risk of pain, injury or disease, humane killing, minimising the risk of predation, reasonable protection from extremes of weather and effects of natural disasters, etc. (Animal Health Australia, 2016).

The effectiveness of producer management of animal welfare risk could be evaluated based on their documented compliance with the relevant standards. For example, since October 2017, all producers accredited under the voluntary LPA scheme must demonstrate that their on-farm handling of livestock is consistent with the Australian Standard. Farms are randomly audited and the results recorded in a register based on property ID code.

4.14 Energy

A farm's dependency on energy entails a risk that the cost of energy use will increase significantly in future. Energy may be consumed directly (on-farm) or indirectly (in processes associated with production and transport of inputs). Energy dependency risk therefore has two components: the quantity of different types of energy consumed (directly and indirectly), and the price of each type of energy.

Wiedemann, McGahan, et al. (2016) estimate total fossil-fuel energy demand for a range of eastern Australian beef cattle farms to be 3.9-12.5 MJ/kg LW, with on average 58% of this being direct energy consumption (dominated by diesel), and the remainder indirect energy

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[14] See https://www.mla.com.au/meat-safety-and-traceability/red-meat-integrity-system/about-the-livestock-production-assurance-program/; http://jbssa.com.au/OurCompany/OurQualityPromise/JBSFarmAssurance/default.aspx and https://animalhealthaustralia.com.au/jd-cattle-tools/ (accessed 3 January 2019).

[15] http://kb.rspca.org.au/what-is-the-australian-legislation-governing-animal-welfare_264.html

[16] http://www.animalwelfarestandards.net.au/sheep/ (accessed 3 January 2019).

consumption associated with fertiliser production and supplementary feed. Fuel costs for beef producers averaged A$0.10/kg LW for northern producers and A$0.07/kg LW for southern producers in 2016-2017, or about 5% and 3% of total costs, respectively.[17] As this is a relatively small component of total costs, energy use is not considered to be a material natural capital risk for Australian pasture-fed beef production. Nevertheless, if a lender wished to benchmark a producer's energy use, this could be done relatively easily by applying regionally appropriate energy conversion factors (DOEE, 2018) to farm fuel, fertiliser and supplementary feed consumption data.

4.15 Greenhouse gas emissions

Beef production (excluding feedlots) accounted for 33 million tonnes of carbon dioxide equivalent ($MtCO_2$-e) in 2018: 46% of Australia's agricultural emissions and 6% of national emissions (DOEE, 2015). 90% of these emissions arise from enteric fermentation.[18] When cattle digest feed, up to 12% of feed energy is lost in the form of methane gas – a by-product of microorganisms that live in the rumen (MLA, 2015). A single cow can release up to 500 litres of methane per day.[19] Methane is a powerful greenhouse gas, with about 28 times the global warming effect of carbon dioxide over a 100-year period, or 84 times the global warming effect of carbon dioxide over a 20-year period (IPCC 2013). Other potentially significant sources of GHG emissions associated with beef production (but attributed elsewhere in the national greenhouse gas inventory) include emissions from land use change (mainly land clearing) and loss of soil carbon. Direct land use change emissions associated with deforestation for beef cattle pastures in Australia have been estimated at 24.2 Mt CO_2-e/year over 2006-2010, with associated soil carbon losses adding a further 1.7 Mt CO_2-e/year, over the same period (Wiedemann et al., 2015).

GHG emissions can represent a risk in two different ways. First, environmental regulations could internalise and/or increase the cost of GHG emissions in future. Second, in the case of enteric and soil carbon emissions, high levels are an indicator of inefficient production: enteric emissions suggest that energy in feed that could have been converted into meat is being wasted, while soil carbon emissions are associated with deteriorating soil quality (see section 4.6).

On a full life cycle basis, Wiedemann et al. (2015) calculate that the GHG emissions intensity of Australian beef farms in the year 2000 was 13.1 kg CO_2-e/kg LW (excluding emissions resulting from land use and land use change). A lender could incorporate assumed per-tonne LW average emissions, priced at different shadow carbon price levels, into their financial analysis, unless the

[17] http://www.agriculture.gov.au/abares/research-topics/surveys/beef#detailed-cost-of-production-findings (accessed 4 January 2019).
[18] http://ageis.climatechange.gov.au/ (accessed 4 January 2019).
[19] http://news.mit.edu/2015/detector-sniffs-out-methane-0305 (accessed 11 August 2017).

farmer can demonstrate that they are taking action to reduce emissions in a way that could be recognised under locally applicable regulations. With respect to land use change emissions, a potential risk would be indicated if a producer has cleared land since 1 January 1990, as such changes are accounted at the national level as an emission liability under the Kyoto Protocol, and this liability could potentially be passed down to the producer in future.

4.16 Other air emissions

Other air emissions from agricultural production could potentially include particulates (dust), drift from pesticide/herbicide application, etc. Although livestock production contributes to major dust storms experienced in Australia (Yapp et al., 2001), which can impact on human health and water quality, it is unlikely that these emissions would represent a material risk at the individual farm level, due to the aggregated nature of the problem.

5 Discussion and conclusions

Livestock grazing has been identified as a major, and growing, contributor to the world's most pressing environmental problems, from climate change to water consumption and pollution, deforestation and biodiversity loss (Steinfeld et al., 2006). The financial sector is exposed to risks associated with beef production's impacts and dependencies on natural capital through its direct lending to the sector, yet it lacks any detailed, context-specific approach to evaluating these risks within the credit risk assessment process. In large part, this is because the relevant risks for agriculture vary considerably by sub-sector and geography, and thus require a detailed understanding of specific contexts. In this paper we have undertaken a bottom-up review of the most likely material natural capital risks for a single sector and geography – Australian beef cattle production – thus demonstrating that a context-specific natural capital credit risk assessment approach is feasible. This adds to a small but growing literature providing evidence to support such risk assessments for different agricultural sectors and geographies (Cojoianu & Ascui, 2018; Georgopoulou et al., 2015; Zeidan et al., 2015).

The exercise shows that a 'natural capital' lens significantly extends the scope historically covered by ECRA, due to the inclusion of natural capital *dependencies* in addition to *impacts*. As Table 1 shows, the inclusion of dependencies approximately doubles the number of material risks that should (ideally) be taken into account. Furthermore, in the past, ECRA for a beef producer might well have addressed only a single impact risk (land contamination). Whilst in theory the scope of environmental impact assessment should always have been more comprehensive, the natural capital framing provides renewed impetus to more holistic thinking.

The case study also highlights some limitations in the concepts of natural capital and ecosystem services, as currently conceived by the financial sector (Natural Capital Coalition, 2018). For example, thinking in terms of natural 'stocks' (such as a standing forest) and ecosystem services ‘flows’ (such as harvested wood products) does not encourage consideration of ambient temperature and weather as important features of the natural environment – yet from a risk perspective in agriculture, these are clearly critical dependencies. Similarly, our analysis demonstrates the importance of considering ‘ecosystem dis-services’ such as weeds, pests and diseases, as well as the positive services more typically focussed upon.

Many challenges to implementing natural capital credit risk assessment in practice remain, however. Agricultural natural capital impacts and dependencies are often difficult to define and measure, because they are complex, multi-dimensional and interconnected (and sometimes still poorly understood). Identifying suitable risk measures is therefore a matter of balancing complexity and comprehensiveness with practicality: a mix of art and science. There is no definitive ‘right’ answer to the question of how to measure a particular risk, but we have shown that there are, for nearly all of the identified risks, some options currently available to begin assessment. Only by starting to collect such information, and then comparing it with loan performance, will lenders be able to evaluate the effectiveness of different metrics and measurement options (Katchova & Barry, 2005).

There is of course a trade-off between the cost of obtaining and analysing information, and the associated benefit – and at present, neither side of this equation has been adequately measured, with respect to sector- and geography-specific natural capital credit risk assessment. This is an important area for further research (Weber, 2012; Weber, Scholz, & Michalik, 2010). The benefit should not only consider the lender’s improved ability to identify, avoid and/or price natural capital risk due to a reduction in information asymmetry (Akerlof, 1970), but also the potential benefits for the borrower that could result from understanding risks, and mitigation options or best practices, of which they might not previously have been aware. In general, more research is required that explores the links between natural capital impacts and dependencies, and farm financial performance.

Another challenge is that credit risk assessment is by its very nature a forward-looking process that requires judgements to be made about an unknown future. Natural capital credit risk assessment therefore differs fundamentally from backward-looking natural capital accounting, for example as practiced under the UN System of Environmental-Economic Accounting, or SEEA (European Commission, OECD, United Nations, & World Bank, 2013; United Nations et al., 2014). Nevertheless, a forward-looking risk assessment can start from an assessment of the historical situation, and convergence with frameworks such as SEEA (for example by sharing concepts and definitions, thus promoting consistency of data) is certainly desirable. A qualitative forward-looking risk evaluation could start by rating the historical/current risk, moderating it according to the future projection, and then moderating it by an assessment of the farmer’s ability to mitigate the risk. Whether (and how) such assessments of individual risk indicators could be weighted and combined into an overall risk assessment – as opposed to relying on credit officers' subjective integration – is another area where more research is urgently needed.

In order to implement agricultural natural capital credit risk assessment effectively, banks and/or research providers will need to start investing in spatial 'Big Data' capabilities, for example using Geographical Information Systems (GIS), which has not yet been widely adopted in the financial sector (Cojoianu et al. 2015). Many of the data sources we have identified for beef production in Australia are already GIS-based (e.g. rainfall and other climatic data, biodiversity, weeds etc.), and by collecting and collating their own data, elicited through the lending application process (Goss & Roberts 2011), banks may begin to benefit from the ability to detect systemic risks (and opportunities) across a portfolio. Such systemic effects are likely to be relevant because many of the natural capital and sustainability issues in agriculture involve long-term, large-scale processes, where systemic understanding is still emergent. Ideally some form of data-sharing process – such as various initiatives underway in the area of product sustainability claims (Gale, Ascui, & Lovell, 2017) – would develop, so that such information would not remain siloed within individual lenders, where its potential utility is significantly decreased.

Finally, truly valuing natural capital in agricultural lending will require radical transformations in awareness and culture both within lending organisations and across the banking sector. At present, only a handful of the world's banks have signed up to the Natural Capital Declaration. It is likely that, as experienced in the past with environmental risk, banks may be concerned that asking their customers too many difficult questions may result in them being competitively disadvantaged (Coulson, 2002, 2009). Furthermore, at the level of individual credit assessment officers, focussing primarily on financial information is a powerful mind-set which will need to be actively transformed to a new framing that is inclusive of natural capital impacts and dependencies. There is an urgent need for both critical and empirical social science research which addresses the many challenges associated with achieving this transformation, if the goal of managing our natural capital with the same diligence that we manage our financial capital is to be achieved, in the relatively short time before that natural capital is irrevocably depreciated.

References

ABARES. (2015). *Australian beef: Financial performance of beef cattle producing farms, 2012–13 to 2014–15*. Canberra: ABARES research report prepared for Meat & Livestock Australia.

ABARES. (2018). Beef farms. Retrieved February 7, 2019, from http://www.agriculture.gov.au/abares/research-topics/surveys/beef

ABS. (2010). Measures of Australia's Progress, 2010 - Salinity. Retrieved August 15, 2017, from http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by Subject/1370.0~2010~Chapter~Salinity (6.2.4.4)

Akerlof, G. A. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *The Quarterly Journal of Economics*, *84*(3), 488. https://doi.org/10.2307/1879431

ALFA. (2013). *Grass fed versus grain fed beef*. Sydney: Australian Lot Feeders' Association.

Altman, E. I., & Saunders, A. (1997). Credit risk measurement: Developments over the last 20 years. *Journal of Banking & Finance*, *21*(11–12), 1721–1742. https://doi.org/10.1016/S0378-4266(97)00036-8

Animal Health Australia. (2016). *Australian animal welfare standards and guidelines for cattle*. Deakin, ACT: Animal Health Australia.

Australian Organic. (2017). *Australian Organic Market Report 2017*. Nundah: Australian Organic Ltd.

Bebbington, J., & Gray, R. (1993). Corporate accountability and the physical environment: Social responsibility and accounting beyond profit. *Business Strategy and the Environment*, *2*(2), 1–11. https://doi.org/10.1002/bse.3280020201

Caouette, J. B., Altman, E. I., Narayanan, P., & Nimmo, R. (2010). *Managing Credit Risk: The Great Challenge for the Global Financial Markets* (2nd ed.). Hoboken, NJ: John Wiley & Sons.

Chilcott, C. R., Paton, C. J., Quirk, M. F., & McCallum, B. S. (2003). *Grazing Land Management Education Package Workshop Notes – Burnett*. North Sydney: Meat and Livestock Australia.

Cojoianu, T. F., & Ascui, F. (2018). Developing an evidence base for assessing natural capital risks and dependencies in lending to Australian wheat farms. *Journal of Sustainable Finance & Investment*, *8*(2), 95–113. https://doi.org/https://doi.org/10.1080/20430795.2017.1375776

Cojoianu, T. F., Hoepner, A. G. F., Rajagopalan, R. D., & Borth, D. S. (2015). *NCD Scoping Study: Towards Including Natural Resource Risks in Cost of Capital*. Oxford: Natural Capital Declaration.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., … van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630), 253–260. https://doi.org/10.1038/387253a0

Costanza, R., & Daly, H. E. (1992). Natural Capital and Sustainable Development. *Conservation*

Biology, *6*(1), 37–46. https://doi.org/10.1046/j.1523-1739.1992.610037.x

Coulson, A. B. (2002). *A Benchmarking Study: Environmental Credit Risk Factors in the Pan-European Banking Sector*. London: ISIS Asset Management.

Coulson, A. B. (2009). How should banks govern the environment? Challenging the construction of action versus veto. *Business Strategy and the Environment*, *18*(3), 149–161. https://doi.org/10.1002/bse.584

Coulson, A. B., & Dixon, R. (1995). Environmental risk and management strategy: the implications for financial institutions. *International Journal of Bank Marketing*, *13*(2), 22–29. https://doi.org/10.1108/02652329510078668

Delamaide, D. (2008). Environmental risk management: A Growing Trend in Commercial Lending. *The Secured Lender*, *64*(3), 56–58.

Dell'Atti, S., & Trotta, A. (2016). *Managing reputation in the banking industry: Theory and practice*. (S. Dell'Atti & A. Trotta, Eds.). Cham: Springer. https://doi.org/10.1007/978-3-319-28256-5

Dobler, M., Lajili, K., & Zéghal, D. (2014). Environmental Performance, Environmental Risk and Risk Management. *Business Strategy and the Environment*, *23*(1), 1–17. https://doi.org/10.1002/bse.1754

DOEE. (2015). *Australia's emissions projections 2018*. Canberra: Department of the Environment and Energy, Australia.

DOEE. (2018). *National Greenhouse Accounts Factors: Australian National Greenhouse Accounts*. Canberra: Department of the Environment and Energy, Australia.

Dominati, E. J., Patterson, M., & Mackay, A. D. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, *69*(9), 1858–1868. https://doi.org/10.1016/j.ecolecon.2010.05.002

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, *11*(2), 130–141. https://doi.org/10.1002/bse.323

European Commission, OECD, United Nations, & World Bank. (2013). *System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting*. New York, NY: United Nations.

Gale, F., Ascui, F., & Lovell, H. (2017). Sensing reality? New monitoring technologies for global sustainability standards. *Global Environmental Politics*, *17*(2), 65–83. https://doi.org/10.1162/GLEP_a_00401

Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Hontou, V., Gakis, N., Lalas, D., … Zavras, V. (2015). A methodological framework and tool for assessing the climate change related risks in the banking sector. *Journal of Environmental Planning and Management*, *58*(5), 874–897. https://doi.org/10.1080/09640568.2014.899489

GHD. (2015). *Priority list of endemic diseases for the red meat industries*. North Sydney: Meat and Livestock Australia.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative* *research*. New York, NY: Aldine.

Goss, A., & Roberts, G. S. (2011). The impact of corporate social responsibility on the cost of bank loans. *Journal of Banking & Finance*, *35*(7), 1794–1810. https://doi.org/10.1016/j.jbankfin.2010.12.002

Hamlyn-Hill, F. (2016). Water Requirements for Cattle. Retrieved October 21, 2016, from https://futurebeef.com.au/knowledge-centre/nutrition/water-requirements/

Helm, D. (2014). Taking natural capital seriously. *Oxford Review of Economic Policy*, *30*(1), 109–125. https://doi.org/10.1093/oxrep/gru005

Henry, K. (2016). Dr Ken Henry AC Speech – Advancing Australia's Natural Capital. Retrieved October 19, 2016, from http://news.nab.com.au/dr-ken-henry-ac-speech-advancing-australias-natural-capital/

Higgins, S., Moser, L., & Schmidt, K. (2016). *Drought Risk Management for Beef Cattle Farms*. Lexington: University of Kentucky College of Agriculture, Food and Environment.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. (T. F. Stocker, D. Qin, G.-K. Plattner, M. M. B. Tignor, S. K. Allen, J. Boschung, … P. M. Midgley, Eds.). Cambridge, UK and New York, NY: Cambridge University Press.

James, P. (1994). Business environmental performance measurement. *Business Strategy and the Environment*, *3*(2), 59–67. https://doi.org/10.1002/bse.3280030208

Jones, R., & Sinden, J. (2006). The economic cost of weeds in pasture systems. In *The Grassland Society of NSW Inc. 21st Annual Conference*. Wagga Wagga: The Grassland Society of NSW Inc.

Jorion, P. (2007). *Financial Risk Manager Handbook*. Hoboken, NJ: John Wiley & Sons.

Karfs, R. A., Abbott, B. N., Scarth, P. F., & Wallace, J. F. (2009). Land condition monitoring information for Reef catchments: A new era. *Rangeland Journal*, *31*(1), 69–86. https://doi.org/10.1071/RJ08060

Katchova, A. L., & Barry, P. J. (2005). Credit risk models and agricultural lending. *American Journal of Agricultural Economics*, *87*(1), 194–205. https://doi.org/10.1111/j.0002-9092.2005.00711.x

KPMG. (2014). *Natural Capital at Risk*. KPMG.

Kunhikrishnan, A., Thangarajan, R., Bolan, N. S., Xu, Y., Mandal, S., Gleeson, D. B., … Naidu, R. (2016). Functional Relationships of Soil Acidification, Liming, and Greenhouse Gas Flux. *Advances in Agronomy*, *139*, 1–71. https://doi.org/10.1016/bs.agron.2016.05.001

Land Commodities. (2012). *The Australian Wheatbelt - An Introduction for Investors*. Baar: Land Commodities.

Mengze, H., & Wei, L. (2015). A comparative study on environment credit risk management of commercial banks in the Asia-Pacific Region. *Business Strategy and the Environment*, *24*(3), 159–174. https://doi.org/10.1002/bse.1810

MLA. (2015). *More meat, milk and wool: less methane*. Sydney: Meat and Livestock Australia.

Mukherjee, N., Zambon, S., & Lucius, H. (2013). *Do banks manage reputational risk? A case study of European Investment Bank*. Dublin: The Society of Actuaries in Ireland.

NAB. (2015). *Impact of El Niño on Australian farm GDP*. Melbourne: National Australia Bank.

NAB. (2018). *Natural Value @ NAB*. Melbourne: National Australia Bank.

Natural Capital Coalition. (2016). *Natural Capital Protocol*. London: Natural Capital Coalition. https://doi.org/www.naturalcapitalcoalition.org/protocol

Natural Capital Coalition. (2018). *Connecting Finance and Natural Capital: A Supplement to the Natural Capital Protocol*. London: Natural Capital Coalition.

Natural Capital Declaration. (2012). *The Natural Capital Declaration*. Oxford: Natural Capital Declaration.

NFF. (2012). Farm Facts. Retrieved December 5, 2016, from http://www.nff.org.au/farm-facts.html

Pearce, D. W. (1988). Economics, equity and sustainable development. *Futures*, *20*(6), 598–605.

Peters, G. M., Wiedemann, S. G., Rowley, H. V., & Tucker, R. W. (2010). Accounting for water use in Australian red meat production. *International Journal of Life Cycle Assessment*, *15*(3), 311–320. https://doi.org/10.1007/s11367-010-0161-x

Pettit, C. (2011). *Land Condition Guide: Barkly District*. Darwin: Department of Primary Industry and Resources, Northern Territory.

PwC. (2011). *The Australian Beef Industry: The Basics*. PricewaterhouseCoopers.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a

Ryan, T. (2010). *The Australian fertilizer industry - values and issues*. Newcastle: Meta Economics Consulting Group.

Sbrocchi, C., Davis, R., Grundy, M., Harding, R., Hillman, T., Mount, R., … Cosier, P. (2015). *Technical Analysis of the Australian Regional Environmental Accounts Trial*. Sydney: Wentworth Group of Concerned Scientists.

Schumacher, E. F. (1973). *Small is Beautiful: A Study of Economics As If People Mattered*. New York, NY: Harper & Row.

Simpson, R., Richardson, A., & McLaughlin, M. (2010). *Review of phosphorus availability and utilisation in pastures for increased pasture productivity*. North Sydney, NSW, Australia: Meat and Livestock Australia. https://doi.org/10.1159/000117083

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & de Haan, C. (2006). *Livestock's long shadow: environmental issues and options*. Rome: Food and Agriculture Organization of the United Nations.

Strauss, A. L., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Thousand Oaks: Sage Publications.

Swinton, S. M., Lupi, F., Robertson, G. P., & Hamilton, S. K. (2007). Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics*, *64*(2), 245–252. https://doi.org/10.1016/j.ecolecon.2007.09.020

TEEB. (2008). *The Economics of Ecosystems and Biodiversity: An interim report*. Geneva: United Nations Environment Programme.

Thompson, P. (1998). Bank lending and the environment: Policies and opportunities. *International Journal of Bank Marketing*, *16*(6), 243–252. https://doi.org/10.1108/02652329810241384

Thompson, P., & Cowton, C. J. (2004). Bringing the environment into bank lending: Implications for environmental reporting. *British Accounting Review*, *36*(2), 197–218. https://doi.org/10.1016/j.bar.2003.11.005

United Nations, European Commission, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, & The World Bank. (2014). *System of Environmental-Economic Accounting 2012: Central Framework*. New York, NY: United Nations.

van den Belt, M., & Blake, D. (2015). Investing in Natural Capital and Getting Returns: An Ecosystem Service Approach. *Business Strategy and the Environment*, *24*(7), 667–677. https://doi.org/10.1002/bse.1895

Viscarra Rossel, R. A., Webster, R., Bui, E. N., & Baldock, J. A. (2014). Baseline map of organic carbon in Australian soil to support national carbon accounting and monitoring under climate change. *Global Change Biology*, *20*(9), 2953–2970. https://doi.org/10.1111/gcb.12569

Wang, X., Bjerg, B. S., Choi, C. Y., Zong, C., & Zhang, G. (2018). A review and quantitative assessment of cattle-related thermal indices. *Journal of Thermal Biology*, *77*, 24–37. https://doi.org/https://doi.org/10.1016/j.jtherbio.2018.08.005

Weber, O. (2012). Environmental Credit Risk Management in Banks and Financial Service Institutions. *Business Strategy and the Environment*, *21*(4), 248–263. https://doi.org/10.1002/bse.737

Weber, O., Fenchel, M., & Scholz, R. W. (2008). Empirical analysis of the integration of environmental risks into the credit risk management process of European banks. *Business Strategy and the Environment*, *17*(3), 149–159. https://doi.org/10.1002/bse.507

Weber, O., Scholz, R. W., & Michalik, G. (2010). Incorporating sustainability criteria into credit risk management. *Business Strategy and the Environment*, *19*(1), 39–50. https://doi.org/10.1002/bse.636

Wiedemann, S. G., Henry, B. K., McGahan, E. J., Grant, T., Murphy, C. M., & Niethe, G. (2015). Resource use and greenhouse gas intensity of Australian beef production: 1981-2010. *Agricultural Systems*, *133*, 109–118. https://doi.org/10.1016/j.agsy.2014.11.002

Wiedemann, S. G., McGahan, E., Murphy, C., & Yan, M.-J. (2016). Resource use and environmental impacts from beef production in eastern Australia investigated using life cycle assessment. *Animal Production Science*, *56*(5), 882–894. https://doi.org/10.1071/AN14687

Yapp, G., Munro, R., Barson, M., Chartres, C., Hill, M., & Prendergast, B. (2001). *Environmental Factors Affecting Australia's Livestock Industries*. Kingston, ACT: Bureau of Rural Sciences.

Zeidan, R., Boechat, C., & Fleury, A. (2015). Developing a Sustainability Credit Score System. *Journal of Business Ethics*, *127*(2), 283–296. https://doi.org/10.1007/s10551-013-2034-2

Table 1: Key natural capital risks, example indicators and measurement options for Australian beef production[20]

Theme	Risk factor	Impact risk	Dependency risk	Example indicators	Example data sources
Water	Water availability	N/A	Insufficient rainfall to produce pasture required to meet livestock grazing needs	Region-specific average growing season rainfall quantity and variability	Bureau of Meteorology or farm-specific rainfall datasets; regional outputs from climate models
				Average pasture water use efficiency, compared with benchmarks	Producer records
	Water use	Water used is non-renewable, extracted beyond its renewal rate, or diverted from other ecosystem uses	Water supply is insufficient to meet total water demand	Average total water consumption per DSE, compared with benchmarks	Producer records
				% stock water use that meets impact criteria	
	Water quality	Negative effects on the quality of surface or sub-surface water	Water is not of sufficient quality to maintain health and/or productivity	Frequency of poor stock drinking water quality episodes	Producer records
Weather and climate	Temperature extremes	N/A	Mortality, lower productivity and/or increased costs due to exposure to temperature extremes and extreme weather events	Frequency, severity and duration of heat and cold stress events	Bureau of Meteorology or farm-specific datasets; regional outputs from climate models
	Extreme weather			Frequency, severity and duration of extreme weather events	Australian Climate and Weather Extremes Monitoring System or producer records; regional outputs from climate models
Soil	Soil quality	Negative effects on soil properties	Lower productivity due to poor soil quality	Average soil pH (acidity)	Producer records or soil maps
				Average soil salinity	Producer records or soil maps
				Average soil organic carbon	Producer records or soil maps
				Maintenance of ground cover	Producer records, aerial/satellite imagery or soil maps
	Fertiliser use	Inputs to fertiliser manufacture may be priced at higher levels in future	Lower productivity due to deficiency of key nutrients	Quantity and cost of fertiliser, priced at different levels	Producer records
		Fertiliser application results in water pollution and/or greenhouse gas emissions		Frequency and severity of reportable water pollution	Producer records; environmental protection agency data

[20] Restricted to rain-fed pasture grazing, excluding irrigation and feedlot production.

				events	
	Contamination and waste	Risk that land may be contaminated with various forms of waste	N/A	Number of reportable contaminated land sites	Producer records; environmental protection agency data
Biodiversity and ecosystems	Biodiversity	Negative effects on biodiversity or habitats	Ecosystem services such as pollination become unavailable	Presence of threatened species or communities; quality of biodiversity management	Biodiversity maps; producer records
	Pasture composition	Negative effects on pasture composition	Lower productivity and/or increased costs due to loss of optimal pasture composition	Proportion of farm in 'C' or 'D' condition	Producer records; land maps
	Weeds	Increased incidence of weeds, pests or diseases	Lower productivity and/or increased costs due to weeds, pests or diseases	Proportion of farm in 'C' or 'D' condition	Producer records; land maps
	Pests and diseases			Farm pest/disease incidence levels compared with benchmarks; biosecurity accreditation	Producer records; accreditation schemes
	Animal welfare	Negative effects on welfare of farmed animals	Lower productivity and/or costs due to poor animal welfare	Animal welfare accreditation	Producer records; accreditation schemes
Energy	Energy use	Energy may be priced at higher levels in future	Higher costs due to inefficient use of energy	Direct and indirect energy use, priced at different levels	Producer records
Air emissions	Greenhouse gas emissions	Emissions of greenhouse gases may be priced at higher levels in future	N/A	Average enteric fermentation emissions, priced at different levels	Producer records; national greenhouse gas accounting data
				Amount of forested land cleared since 1 January 1990	Producer records; satellite data; national greenhouse gas accounting data
	Other air emissions	Other air emissions such as particulates (dust) or drift from pesticide/herbicide application may negatively affect human health, air quality or biodiversity	N/A	N/A (unlikely to represent material risks)	-